Designing LED Backlights

June, 2010

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Senior Applications Engineer – Display Products
Agenda

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► Brief Market Information
► LCD Module Block Diagram
► LED Backlighting Types and Dimming Modes
► LED Backlight System Design Challenges
► Key Requirements for LED Drivers
► Proposed Freescale LED Driver Solutions
  - Notebook Applications
  - Monitors Applications
  - TV Applications
► Examples of End Products using Freescale LED Driver Solutions
► Summary
**Introduction**

- LED backlights dominate the smaller LCD display market
  - Cell phone, GPS, PDA

- Larger displays (20” plus) have traditionally used Cold Cathode Fluorescent Lamps (CCFLs)

- LEDs are now penetrating larger LCD modules
  - Notebooks have the largest adoption today
  - Monitors and TVs are a rapidly growing market
Introduction, cont’d

- LEDs have many advantages compared to CCFL
  - Point source characteristics enable more flexible backlight architectures
    - Enables thinner backlight designs
    - Enables advanced backlight architectures
  - Higher efficacy (more light per Watt) – white LEDs only
  - Longer lifetime (50,000 hours versus <10,000 hours)
  - Dimmable – accurate with infinite steps
  - Low voltage drivers reduce complexity
  - Environmentally friendly (CCFLs contain mercury)
  - Rugged – CCFLs are glass and can break easily
  - RGB specific advantages
    - Wider color gamut
    - Tunable white point
The LEDs used in backlighting are categorized in two major groups

1. Current capability
   - Standard LED – drive current < 50mA
   - High current LED – drive current 50 – 150 mA
   - High power LED – drive current 150 – 1000mA+

2. Color
   - White LEDs
   - Red, green and blue LEDs
     - Combined to make white

LED forward voltage depends on color
   - Red ~ 2V, green ~ 3.5V, blue/white ~3.5 – 4V
Introduction, cont’d

► Strong requirements such as high picture quality, high system efficiency, reduced PCB area and low cost are driving LED power management solutions to become highly integrated and optimized.

► System designers are facing significant challenges as they must consider many LED power management options when designing LED drivers for LCD backlighting applications.

► Meeting the overall design requirements of high picture quality in the smallest PCB area and at the lowest cost would not be possible to achieve without integrated LED power management solutions.
### Brief Market Information

**Global LED LCD TV Market Forecast**

*Source: January 13, 2010 | Displaybank*

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**LED LCD TV Market Forecast**

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LCD Module Block Diagram

LCD Application—LED Backlight Drivers

- Backlight Drivers
  - Power Management
  - Video Processing/Timing Controller
  - Power
  - Video Data
  - Backlight Module

Freescale Focus Areas

Freescale Technology
LED Backlighting Types and Dimming Modes

► **Edge-lit backlight**

- LEDs along edge of display
- Generally used in smaller panels
  - Now in TV’s up to 40”
- Enables super thin backlight
  - <2 mm thick for notebook
- Uniformity worst than direct backlight
  - Especially for larger displays

► **Direct backlight**

- LED array behind LCD
- Used in larger panels
  - 30”+
- Enables advanced architectures
  - Scanning and local dimming
- Good uniformity
LED Backlighting Types and Dimming Modes, cont’d

Two major dimming modes are used for LED backlight applications:
- Global dimming (All LED strings are dimmed together)
- Local dimming (LED strings are dimmed independently)

Local dimming improves contrast ratio and power consumption
• Backlight is divided into a number of zones
• The backlight is then adjusted depending on the picture content
  - Contrast ratio improvements to >500,000:1 possible
    - Standard LCD ~ 5000:1
  - Reduces power dissipation up to 50% (depends on video content)
    - The backlight consumes 30%+ of power in LCD-TVs
LED Backlighting Types and Dimming Modes, cont’d

Direct Type LED Backlighting Local Dimming Block Diagram

- Video: DVI
- Host: USB
- FPGA
- SPI
- MCU
- 12 LEDs per block

Drivers:
- Driver 1
- Driver 2
- Driver 3
- Driver 4
- Driver 5
- Driver 6
- Driver 7
- Driver 8

High speed differential interface

20” Monitor Screen

12 LEDs per string, 64 LED strings, total 768 LEDs (I = 80mA)
Edge-Lit Type LED Backlighting Local Dimming Block Diagram

- **Host**
  - USB
  - Video
    - DVI

- **FPGA**
  - SPI

- **MCU**

- **LED Driver**
  - 10 LEDs
  - 20" Monitor Screen
  - 10 LEDs per string, 16 LED strings, total 160 LEDs (I = 80mA)

**LED Backlighting Types and Dimming Modes, cont’d**

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LED Backlighting Types and Dimming Modes, cont’d

Toshiba 46” TV demo – Power consumption with and without local dimming

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LED Backlight System Design Challenges

1) Drawbacks of the LCD technology
   • Limited contrast ratio (5000:1 only for a good quality display)
   • Motion blur (often seen in moving pictures)
   • Visual artifacts (water fall noise)

2) LED forward voltage mismatch
   • Creates power dissipation issues for linear LED drivers
   • Decreases the overall system’s efficiency and increases cost

3) Audible noise issues
   • MLCC caps used in switching regulators create audible noise issues

4) ESD/EMC issues
   • System requirements such as the IEC61000-4-2 and IEC61000-4-5 industry standards have to be met for the final end products

5) PCB design
   • 2-layer PCB is the preferred option by the majority of customers due to cost saving reasons and this puts a big challenge on the PCB engineering design

6) Cost
   • Total system solution cost is one of the main drivers for this market, demanding optimum system solutions with minimized BOM
LED Backlight System Design Challenges, cont’d

1) Drawbacks of the LCD technology
   • Limited contrast ratio (5000:1 only for a good quality display)
   • Motion blur (often seen in moving pictures)
   • Visual artifacts (water fall noise)

Advanced LED backlight architectures are used to overcome LCD drawbacks

► Contrast ratio and power consumption can be improved using local dimming
  • Backlight is divided into a number of zones
  • The backlight is then adjusted depending on the picture content
    ▪ Contrast ratio improvements to >500,000:1 possible
      – Standard LCD ~ 5000:1
    ▪ Reduces power dissipation up to 50% (depends on video content)
      – The backlight consumes 30%+ of power in LCD-TVs

► Motion blur can be improved using scanned backlights
  • Backlight is divided into rows
  • Light is scanned down the display at frame rate
  • One or more rows can be illuminated at a time
  • Eye tricked in to seeing faster refresh
  • This removes the blur effect
2) LED forward voltage mismatch

- Creates power dissipation issues for linear LED drivers
- Decreases the overall system's efficiency and increases cost

**LEDs binning should be done to minimize LED voltage forward variation**

► Typical white LED spec’d with $V_F = 3.0\text{V min, 3.6V max}$
  - For a string of 12 LEDs, this means $V_F^{(total)} = 36\text{V to 43.2V}$
  - In reality, statistical distribution may give 2V - 3V variation
  - The linear drivers have to absorb this voltage difference ($V_{VAR}$)
  - In addition, there is a minimum voltage in the drivers needed for the current driver ($V_{MIN}$)
    - Reducing this to a minimum, helps keep power dissipation down
    - However there is a trade off with current accuracy
    - Freescale products typically around 500mV
  - $P_{Diss} = ((n - 1) \times I_{LED} \times (V_{MIN} + V_{VAR})) + I_{LED} \times V_{MIN}$
  - e.g. For 8 channels, driving 50mA LEDs with average variation of 3V
  - $P_{Diss} = ((8 -1) \times 50.10^{-3} \times (0.5 + 3)) + 50.10^{-3} \times 0.5 = 1.08W$

► Dynamic Headroom Control (DHC)
  - To reduce power dissipation, the string voltage ($V_S$) should be kept to a minimum
  - As LED voltage is unknown, fixed output voltage must assume worst case (43.2V)
  - DHC measures the voltage connected to the LED driver and adjusts the output voltage ($V_S$) to the minimum capable of driving the LEDs – 500mV for Freescale drivers
  - Delivers minimum possible dissipation/ highest efficiency for LED driver
LED Backlight System Design Challenges, cont’d

3) Audible noise issues
   - MLCC caps used in switching regulators create audible noise issues

PWM frequency above the audible noise range (e.g. 25 kHz), and suppressed noise MLCC caps (GJ8 series from Murata) should be used.

![Typical Operating Waveforms](image.png)

**Figure 8. Typical Operating Waveforms (FPWM=25kHz, 50% duty)**

**Result of Acoustic Noise Measurement**

- GJ8 1206 10uF
- GJ8 1206 4.7uF
- Standard MLCC 1206 10uF

- Sound Pressure Level is ~60% per ~6 (dB)
- This is commonly used for input filter.

It is need to examine Acoustic Noise Level of New GJ8 series with each equipment of actual design.
4) ESD/EMC issues
   - System requirements such as the IEC61000-4-2 and IEC61000-4-5 industry standards have to be met for the final end products.

ESD protection devices such as TVS arrays in combination with proper PCB lay-out practices should be used to minimize system ESD/EMC issues.

**ESD Types**

- **Direct ESD stress**
  - Generated by contact discharge, up to 6kV in IEC 61000-4-2 standard

- **Indirect ESD stress**
  - ESD conditions are characterized by fast rise time (nsecs).
  - PCB layers induces parasitic capacitance then the C*dV/dt effect induces a parasitic current.

- Generated by air discharge, up to 15kV in IEC 61000-4-2 standard

**ESD Protection methods**

Most IC’s are not protected for ESD conditions higher than 2kV
LED Backlight System Design Challenges, cont’d

5) PCB design

- 2-layer PCB is the preferred option by the majority of customers due to cost saving reasons and this puts a big challenge on the PCB engineering design

Good practices for PCB lay-out design should be followed to get optimum performance. This is often challenging specially when using two layers only.

- Thermal vias are critical for proper power dissipation in QFN packages
  - It has been proven that having 16 thermal vias in the exposed pad of QFN packages between 4x4mm and 7x7mm provides a good thermal pad for proper dissipation
  - The diameter and size of the 16 thermal vias depends on the size of the QFN package

- Ground separation techniques are recommended
  - Separation of power ground and signal ground is recommended, specially for a two-layer PCB design
  - This prevents conducted noise issues into sensitive signals and pins that can cause malfunction in the system

![Diagram showing PCB layout and thermal vias.]
6) Cost

- Total system solution cost is one of the main drivers for this market, demanding optimum system solutions with minimized BOM

Advanced switching power supply architectures are used to integrate critical functions and minimize dependence in external components

- **Internal boost and slope compensation**
  - Eliminates engineering efforts for boost compensation and minimizes external components count

- **PWM phase shifting**
  - The phase shifting feature significantly minimizes the ripple at VOUT, which eliminates the need of using big output caps and prevents audible noise issues
Key Requirements for LED Drivers

► Laptop Applications
  • Global dimming PWM control (10-bits resolution equivalent)
  • Precise LED current matching between channels (± 2%)
  • High precision/linearity at high PWM frequencies (e.g. 25 kHz)
  • High efficiency (85% or higher)
  • Medium output power (6W) and high output voltage (60V)
  • Two-layer PCB design is strongly required
  • Low external components count and reduced PCB area (>> 1 square inch)

► 2) Monitor Applications
  • Global dimming PWM control (10-bits resolution equivalent)
  • Master/Slave configuration for multiple IC operation
  • Precise LED current matching between channels and ICs (± 2%)
  • High precision/linearity at high PWM frequencies (e.g. 25 kHz)
  • High efficiency (85% or higher)
  • High output power (25W) and output voltage (60V)
  • Digital interface (I2C, SMBus or SPI)
  • Two-layer PCB design is required
  • PWM synchronization is desired to remove visual noise artifacts
Key Requirements for LED Drivers, cont’d

► TV Applications
  • Global and local dimming PWM control (10-bits resolution equivalent)
  • Scan mode operation (direct backlight applications only)
  • Master/Slave configuration for multiple ICs operation
  • PWM synchronization capability is required to remove visual noise artifacts
  • Precise LED current matching between channels and ICs (± 1%)
  • High precision/linearity at high PWM frequencies (e.g. 25 kHz)
  • High efficiency (85% or higher)
  • High output power (20W) and high output voltage (60V)
  • Advanced digital interface (LVDS or SPI)
  • Two-layer PCB design is preferred
Proposed Freescale LED Driver Solutions

Laptop Applications – MC34845 device
(Six-channel LED driver with integrated boost, direct PWM control only)

Features
► Input voltage of 6V to 21V
► 2.5A integrated boost
  • 1.2 MHz switching frequency
  • 600 kHz switching frequency
  • 300 kHz switching frequency
► Output voltage up to 60V
► Up to 30mA LED current
► 90%+ efficiency (DC:DC)
► Six-channel current mirror
  • ±2% current matching
► Dynamic headroom control
► Direct PWM input control
  • 100,000:1 PWM dimming range
  • 200ns minimum PWM input pulse
  • Fast 40ns t_R/ 30ns t_F driver
► User programmable OVP
► LED short/open detect
► OTP/OCP/UVLO lockout
► 24-Ld 4x4x0.8mm TQFN package
► -40° C to +85° C temperature range

![Simplified Applications Diagram](image)

Figure 1. Simplified Applications Diagram

ORDERING INFORMATION

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<th>Device</th>
<th>Temperature Range (T_A)</th>
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<td>MC34845BEP/R2</td>
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Tape and Reel depicted with “R2”
Proposed Freescale LED Driver Solutions, cont’d

Laptop Applications – MC34845 device
(Six-channel LED driver with integrated boost, direct PWM dimming control only)

► The overall system efficiency is improved when proper external components are used (e.g. low DCR inductor, schottky diode, etc)
► The ILED channel mismatch holds a current tolerance below +/- 2% for all duties at 25 kHz, which is only possible due to the high speed LED drivers of the device
Proposed Freescale LED Driver Solutions, cont’d

Laptop Applications – MC34846 device
(Six-channel LED driver with integrated boost, four different PWM dimming modes)

FEATURES
► Input voltage of 5V to 24V
► 2.0A integrated boost FET
  • 300 kHz to 1.5 MHz
► Output voltage up to 45V
► Six-channel LED driver
  • Up to 30mA LED current
  • ±1.5% tolerance
► Internal PWM generator
  • 400 Hz – 25 kHz (10-bit resolution)
► PWM frequency conversion
  • 100 Hz to 22 kHz input
► Phase shifting feature
► Direct PWM control mode
  • 200 Hz to 75 kHz
  • 200 ns minimum pulse
► Dynamic headroom control
► Input to synchronize with frame frequency
► User programmable OVP
► LED open/short detection
► OTP, OCP, UVLO fault detection
► 20-Ld QFN 4x4x0.65mm package

ORDERING INFORMATION

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XX SUFFIX EXPOSED PAD
XX SUFFIX (PB-FREE)
98ARE10566D
20-PIN XXXXXX
Laptop Applications – MC34846 device
(Six-channel LED driver with integrated boost, four different PWM dimming modes)

Efficiency is significantly improved when the boost frequency is set to 300 kHz, the 33uH TOKO inductor (1217AS-H-330M) and 1A, 60V Schottky diode are used.

The phase shifting feature significantly minimizes the ripple at VOUT, which eliminates audible noise issues from the MLCC caps.
Monitor/TV Applications – MC34844A device
(10-channel LED driver with integrated boost, I²C interface and integrated PLL)

Features
► Input voltage of 7V to 28V
► Boost output voltage up to 60V, with auto VOUT selection
► 3.0A integrated boost FET
► Up to 80mA LED current / channel
► 10-channel current mirror with ±2% current matching.
► I²C/ SM-bus interface
► 8-bit programmable DAC
► PWM frequency programmable and synchronizable from 100 Hz to 25,000 Hz
► Programmable boost frequency between 150 KHz and 1.2 MHz
► User programmable OVP
► Temperature / optical compensation loops
► Open / Short LED failure protection
► OTP/OCP/UVLO lockout
► 32-Ld QFN 5x5x0.8mm package

Figure 1. Simplified Application Diagram (SM-Bus Mode)

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 Proposed Freescale LED Driver Solutions, cont’d

Monitor/TV Applications – MC34844A device
(10-channel LED driver with integrated boost, I²C interface and integrated PLL)

**MC34844 80V Solution**

**MANUAL MODE (Single Wire Control)**

**Application Conditions:**
- VIN = 24V
- VOUT = 75V
- OVF = 80V
- ISET = 50mA
- Boost Frequency = 300KHz
- LED Channels = 6
- FWM Frequency = 22KHz to 25KHz
Proposed Freescale LED Driver Solutions, cont’d

TV Applications – MC34848 device
(Eight-channel LED driver, supports direct or edge-lit local dimming)

Features
► Input voltage from 12V to 28V
► Drives up to 96 LEDs
► Integrated boost controller with DHC and programmable freq (200 kHz to 1.2 MHz)
► 45V LED drivers
► 8 LED channels with ±1% tolerance
► Up to 80mA LED current / channel, local dimming mode
► Up to 160mA LED current / channel, scan mode (2/8, 3/8, 4/8, 5/8)
► 10-bit independent PWM control per channel: Dimming ratio: >1000:1
► LED current can be controlled independently in both local dimming and scanning mode
► Serial (differential) interface: initial setup (LED current, FPWM, OVP, etc.)
► Integrated PLL for synchronization of boost and PWM frequency for multi-IC operation
► Open / Short LED failure protection
► OTP/OCP/UVLO lockout
► 48-Ld 7x7x1mm QFN package

Figure 1. MC34848 Simplified Application Diagram

<table>
<thead>
<tr>
<th>ORDERING INFORMATION</th>
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</thead>
<tbody>
<tr>
<td>Device</td>
</tr>
<tr>
<td>MC34848EP</td>
</tr>
</tbody>
</table>
Proposed Freescale LED Driver Solutions, cont’d

TV Applications – MC34848 device
(Eight-channel LED driver, supports direct or edge-lit local dimming)

► LED Current
  • Peak LED current of eight LED channels is set using external resistor on ISET pin
  • Up to 80mA for local dimming and up to 160mA for scan mode (2/8, 3/8, 4/8, 5/8)
  • LED current is matched to ±1% between channels/devices

► PWM Dimming
  • PWM frequency range from 177 Hz to 1200 Hz with 1.0 Hz resolution
  • 10-bit independent PWM control per channel: dimming ratio: >1000:1
  • LED current can be controlled independently in all LED channels

► Synchronization
  • Integrated PLL for synchronization of boost and PWM frequency for multi-IC operation
  • Master/Slave mode selected using external RC network at CPLL pin

► Boost controller
  • Integrated DHC minimizes power dissipation in the LED drivers
  • Programmable boost frequency between 200 kHz and 1.2 MHz
  • Over current protection through Q-FET control

► Fault protection
  • LED short and open protection, OVP and thermal shutdown
  • Fault status output for system reporting

► Interface
  • Serial (differential) interface: initial setup (LED current, FPWM, OVP, etc.)
Proposed Freescale LED Driver Solutions, cont’d

TV Applications – MC34848 device
(Eight-channel LED driver, supports direct or edge-lit local dimming)

- The LED channels are phase shifted (staggered) to minimize VOUT ripple
- For local dimming mode, LED current is independently controlled for each of the channels
- The PLL allows synchronization of boost and PWM operating frequency for Master/Slave configuration
The Freescale Advantage

► Experience
  • Assembled expert team with many years LED driver experience
  • System group engaged with major LED backlight vendors for complete solution approach
    ▪ Convert LCD panels to LED backlight
    ▪ Understand all aspect of backlight design
    ▪ Deep understanding of LED design challenges

► Technology
  • Freescale SMARTMOS™ technology
  • Enables integration of high density control logic, with integrated power device and accurate analog control circuits

► Proven capability
  • Our existing custom products are the highest performing LED drivers on the market
  • Standard products offer innovative features and differentiated performance to stand out from the competition
Examples of End-Products using FSL LED Driver Solutions

- The MC34848 device is used in Toshiba REGZA Cinema Series 46SV670U 46-Inch 1080p LCD HDTV with LED Backlight and ClearScan 240, Black
Examples of End-Products Using Freescale LED Driver Solutions

► The MC34845 device is used in the completely redesigned, better-in-every-way MacBook from apple recently released to market

An LED-backlit display of brilliance.

A 13.3-inch glossy widescreen.

The moment you open your new MacBook, its glossy LED-backlit display greets you with glorious, full-screen brightness and brings your photos, movies, and presentations alive with luminous color. The widescreen resolution of 1280 by 800 pixels gives you plenty of room to multitask, yet it's compact enough to take anywhere. And the display is greener than ever: power efficient, free of harmful toxins such as mercury, and made of arsenic-free glass.
Examples of End-Products using Freescale LED Driver Solutions

► The MC34844 device is used in the 23-inch LQ231U1LW31 LED display from Sharp

Sharp has introduced two new displays in its successful range of LCDs with LED background lighting.

The 23-inch LQ231U1LW31 display features 500 cd/m brightness, wide viewing angle of up to 170° in all directions, incredible color depth with 16 million colors and a high static contrast of 600:1 for industry displays. Its anti-reflection coating also helps to ensure that the display remains easily legible even in difficult light conditions. This means the new 23-inch TFT LCD is suitable not only as a screen component for current industrial control units, but also for applications that are used outdoors entirely or in part, e.g. sales and information terminals, ATMs, testing and measurement equipment, boat control systems.

The robust Strong2 product family has also been expanded to include a model with LED backlighting: the new 12.1-inch TFT LCD, LQ121S1LG62, is characterized not only by its extended operating temperature range of -30°C to 80°C and its mechanical robustness, but by its extremely long service life of up to 70,000 hours. It is therefore predestined for use in machine controls that are exposed to extremely harsh conditions.
Summary

► Freescale is highly focused on LED backlight applications for Laptops, Monitors and HDTVs

► System level expertise and Freescale advanced technology provides differentiated and optimized solutions

► Finished end-products are now launched to market using Freescale solutions (e.g. Laptops, Monitors and HDTVs)

► Standard products are now in mass production

► Future road map will address key LED backlight applications (e.g. Edge-Lit global and local dimming)
Thank You

Questions?